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RESEARCH MEMORANDUM

ALTITUDE STARTING TESTS OF A 1000-POUND-THRUST SOLID-PROPELLANT ROCKET

By John L. Sloop, R. James Rollbuhler, and Eugene M. Krawczonek

Lewis Flight Propulsion Laboratory
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RESEARCH MEMORANDUM

ALTITUDE STARTING TESTS OF A 1000-POUND-THRUST SOLID-PROPELLANT ROCKET

By John L. Sloop, R. James Rollbuhler, and Eugene M. Krawczonek

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SUMMARY

Four solid-propellant rocket engines of nominal 1000-pound-thrust were tested for starting characteristics at pressure altitudes ranging from 112,500 to 123,000 feet and at a temperature of -75° F. All engines ignited and operated successfully. Average chamber pressures ranged from 1060 to 1190 pounds per square inch absolute with action times from 1.51 to 1.64 seconds and ignition delays from 0.070 to approximately 0.088 second. The chamber pressures and action times were near the specifications, but the ignition delay was almost twice the specified value of 0.040 second.

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INTRODUCTION

For long-range missiles, the separation of the nose cone from the propulsion part of the missile is desirable in order to improve the aerodynamic characteristics of the nose cone upon re-entering the atmosphere. This separation can be accomplished by the use of small solid-propellant rockets fired so as to decelerate the propulsion unit. Such engines, called "retro rockets", should start and operate throughout an altitude range of sea level to 100,000 feet and over a temperature range of -65° to 165° F (ref. 1).

At the request of the Western Development Division of the Air Research and Development Command, U.S. Air Force, the NACA Lewis laboratory conducted a brief series of starting and operating experiments with proposed retro-rocket engines at pressure altitudes from 112,000 to 123,000 feet and at a temperature of -75° F. Rocket operational parameters were measured and, in addition, temperature measurements were made downstream of the nozzle to aid in predicting the flame temperatures of surfaces in the vicinity of the rocket jet.

The work reported herein is similar to the tests reported in reference 2 except that a different rocket engine was used.

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APPARATUS

The apparatus consisted of a solid-propellant rocket, an altitude tank that provides altitude pressure only, and a cooling system to cool the rocket to the desired temperature. The altitude tank and cooling system are similar to those reported in reference 2 and are shown in figures 1 and 2.

Rocket Engine

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The solid-propellant rocket engines (shown in fig. 3) were supplied by the Phillips Petroleum Company and were designated Douglas Model DM-18 retro-rocket engines. The engine is 22 inches in over-all length with an internal-external burning grain of ammonium nitrate supported by synthetic rubber pads and ignited by a squib energized by 24 volts direct current.

The specified performance temperatures at -65° , 60° , and 165° F are given in reference 1. An extrapolation of these values to -75° F is as follows:

Chamber pressure, lb/sq in. abs	1050
Thrust (vacuum), lb	960
Thrust (sea-level), lb	755
Duration or action time, sec	1.42
Ignition delay, sec	0.040

Instrumentation

The measurements made were: (1) two combustion-chamber pressures, (2) altitude-tank pressure, (3) exhaust-flame temperature, (4) firing-pulse time, and (5) coolant-bath temperature. The first four measurements were recorded on two multichannel oscillographs. Pressures were measured by strain-gage transducers. Exhaust-flame temperatures were measured with 18 Chromel-Alumel thermocouples, positioned as shown in figure 1. Two thermocouple rakes, each containing 9 thermocouples, were located in approximately the same position relative to the exhaust nozzle (fig. 4); the thermocouples of one rake were shielded by a simple shield, as shown by the insert of figure 1. Firing initiation is shown by the start of a 60-cycle trace on the oscillograph record.

PROCEDURE

Prior to the test runs, the rockets were stored in a controlled temperature refrigerator at -75° F for a minimum of 12 hours. After refrigeration they were removed, assembled in the capsule (fig. 1), and mounted on the altitude tank. The coolant pump was started, and coolant fluid was circulated through the system. Until the coolant bath surrounding the rocket engine reached -75° F, all of the coolant was directed through the heat exchanger. When the desired bath temperature was reached, the mixing valve was controlled manually to keep the bath temperature at -75° F. The coolant fluid was circulated at the constant temperature for a time period equal to, or greater than, the time that had elapsed from the removal of the rockets from the refrigerator until the coolant was circulated around the engine at -75° F. These time intervals and the other operating conditions are shown in table I.

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The rocket performance terminology used in presenting the data is defined in the appendix.

RESULTS AND DISCUSSION

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The four rockets ignited and operated successfully. Oscillograph records of chamber pressures are shown in figure 5. The runs are characterized by a rapid pressure rise at the start, followed by a slump and then by a slow or stepwise build-up to the maximum pressure. This is more clearly illustrated in figure 6, where all pressure data are plotted on the same scale.

The chamber-pressure records A and B did not agree in either run 2 or run 4. In each case, the transducer connected to oscillograph B failed to return to its pre-run zero level; the transducers may have been affected by the rocket-chamber temperature. This difference in zero levels amounted to 120 pounds per square inch for run 2 and 150 pounds per square inch for run 4. The pressures were corrected by assuming that the true zero drifted continuously and linearly from the beginning to the end of the run. Consequently, a proportionate part of 120 or 150 pounds per square inch was added to each indicated pressure throughout the run. When this continuous correction to zero is made, the two records agree more closely with each other and with the other runs (e.g., fig. 6).

Data from the pressure records are tabulated in table II. The average chamber pressures ranged from 1060 to 1190 pounds per square inch absolute, which is near the expected value of 1050 pounds per square inch absolute for -75° F. Action times ranged from 1.51 to 1.64 seconds, or slightly longer than the specified time of 1.42 seconds. These values are better than those required in the specifications. The ignition delay, however, ranged from 0.070 to approximately 0.088 second, which is almost twice the value given in the specifications. The ignition-delay value was approximate because the firing initiation failed to record for run two, and for one of the records on run 4.

The rocket jet temperatures are shown on the oscillograph records (fig. 5). The temperatures for the four runs are presented in figures 7 to 10 for both bare and shielded thermocouples. Figure 11 shows a comparison of temperatures at the end of each run for the bare and shielded thermocouples. The peak temperature occurred at the number 3 position, or about 6 inches downstream of the exit for the bare thermocouples, and at the number 2 position, or about 4 inches downstream of the exit for the shielded thermocouples. The temperatures measured with the shielded thermocouples are higher than those measured with the bare thermocouples. This appears to be either an experimental error, such as misalinement between the centerline of the jet and the thermocouple rake, or possibly jet asymmetry. It is also possible that the unshielded thermocouples were cooled, rather than heated, by radiation. The results refute the idea of reference 2 that the peak temperatures may be the result of radiation from the shock or Mach disc. It is likely that, in the present tests, both types of thermocouples are within the shock zone. Reference 3 shows the shock or Mach disc very clearly and shows how it increases in diameter and distance from the nozzle exit for altitudes up to 85,300 feet, the limit of the experiment. The extent of the shock changes for the higher altitudes simulated in the present investigation is not known. The peak temperature obtained in reference 2 was inversely proportional to the pressure, whereas, for the experiments reported herein, little change in peak temperature occurred for a 50-percent change in pressure. It is also interesting to note that the peak temperatures obtained in these experiments and in reference 2 were not greatly different, although the pressure and thrust were greater in the present case.

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Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, July 29, 1957

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APPENDIX - TERMINOLOGY

The following definitions used in this report are taken from reference 1:

Ignition time:	Time between zero time and 75 percent of maximum pressure
Burning time:	Interval between 10 percent of maximum pressure and time when pressure begins to drop sharply near end
Action time:	Interval between pressure rise of 10 percent of maximum pressure and pressure fall to 10 percent of maximum pressure
Pressure, average chamber:	Area under pressure-time curve between 10-percent points, divided by action time
Pressure, maximum:	Highest pressure developed by rocket engine under any operating condition

REFERENCES

1. Anon.: Drawing No. 7607429 - Model DM-18 - Retro Rocket Engine. Santa Monica Div., Douglas Aircraft Co., Inc., July 16, 1956.

2. Sloop, John L., and Krawczonek, Eugene M.: Altitude Starting Tests of a Small Solid-Propellant Rocket. NACA RM E57F21, 1957.

3. Balwanz, W. W., and Ward, E. W.: Interaction Between Electromagnetic Waves and Flames. Pt. I - The Effect of Altitude on Rocket-Motor Flame Geometry. Rep. 4232, Naval Res. Lab., Oct. 30, 1953.

TABLE I. - OPERATING CONDITIONS

Run	1	2	3	4
Rocket	112	104	101	105
Igniter	I41-34-57	I41-36-57	I41-35-57	I41-33-57
Refrigeration time, hr	19	12	12	12
Time with rocket temperature above -75° F, hr	2	1	$1\frac{1}{2}$	1
Time maintained at -75° F in capsule, hr	$2\frac{1}{2}$	1	$1\frac{1}{2}$	1
Pressure altitude, ft	120,000	113,000	112,500	123,000

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TABLE II. - DATA OBTAINED FROM PRESSURE RECORDS

	Run					
	1, oscillograph A	2, oscillograph A	2, oscillograph B	3, oscillograph A	4, oscillograph A	4, oscillograph B
Ignition time, sec	0.070	≈0.088	≈0.087	0.078	≈0.073	0.077
Burning time, sec	1.455	1.366	1.368	1.427	1.355	1.355
Time to first pressure rise, sec	.015	.015	.015	.015	.015	.015
Action time, sec	1.637	1.535	1.535	1.562	1.512	1.511
Average chamber pressure, lb/sq in. abs	≈1130	1190	1180	1060	1130	1100
Maximum pressure, lb/sq in. abs	≈1300	1375	1350	1300	1295	1240

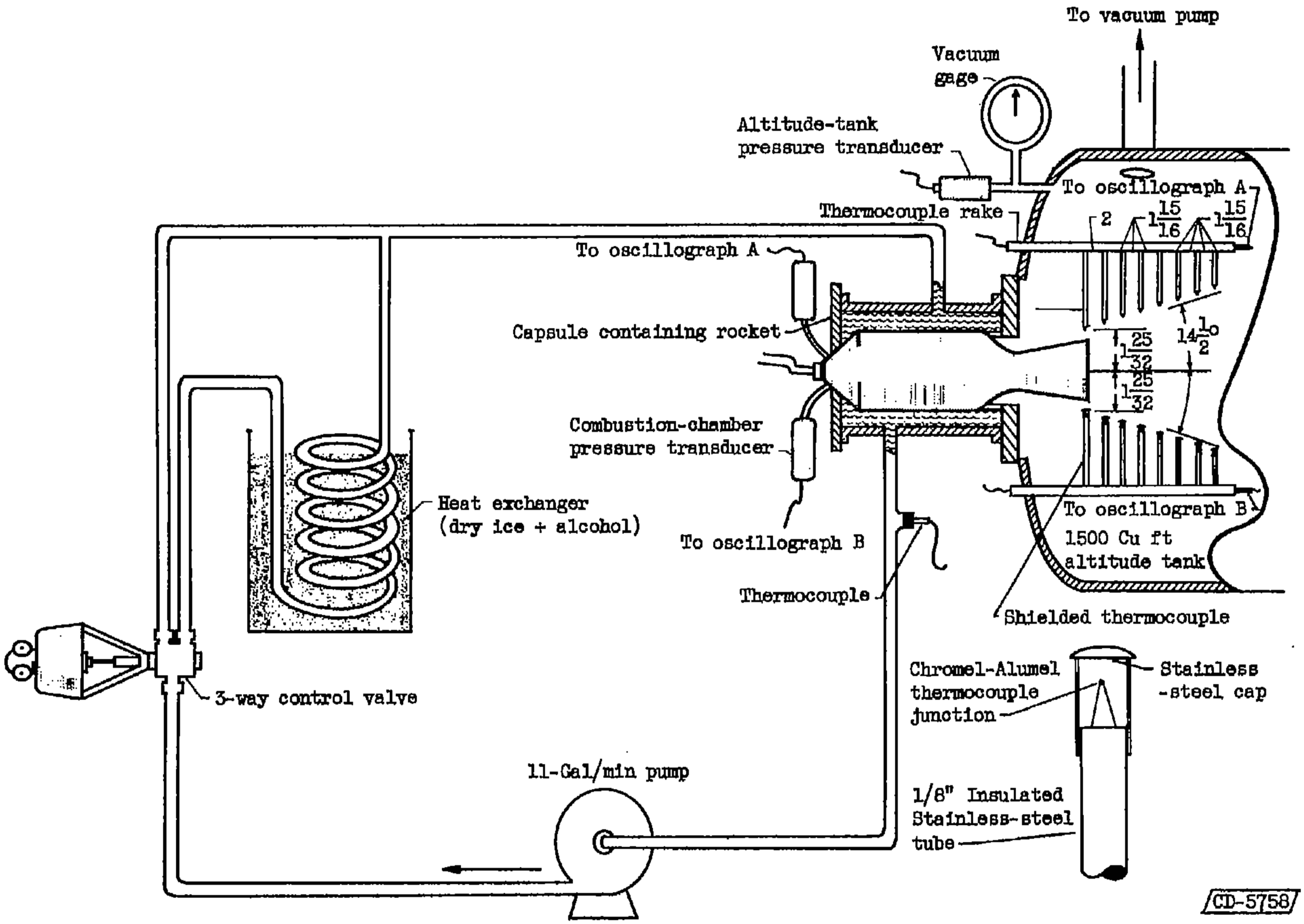

Figure 1. - Layout of coolant system and mounting of engine to altitude tank.

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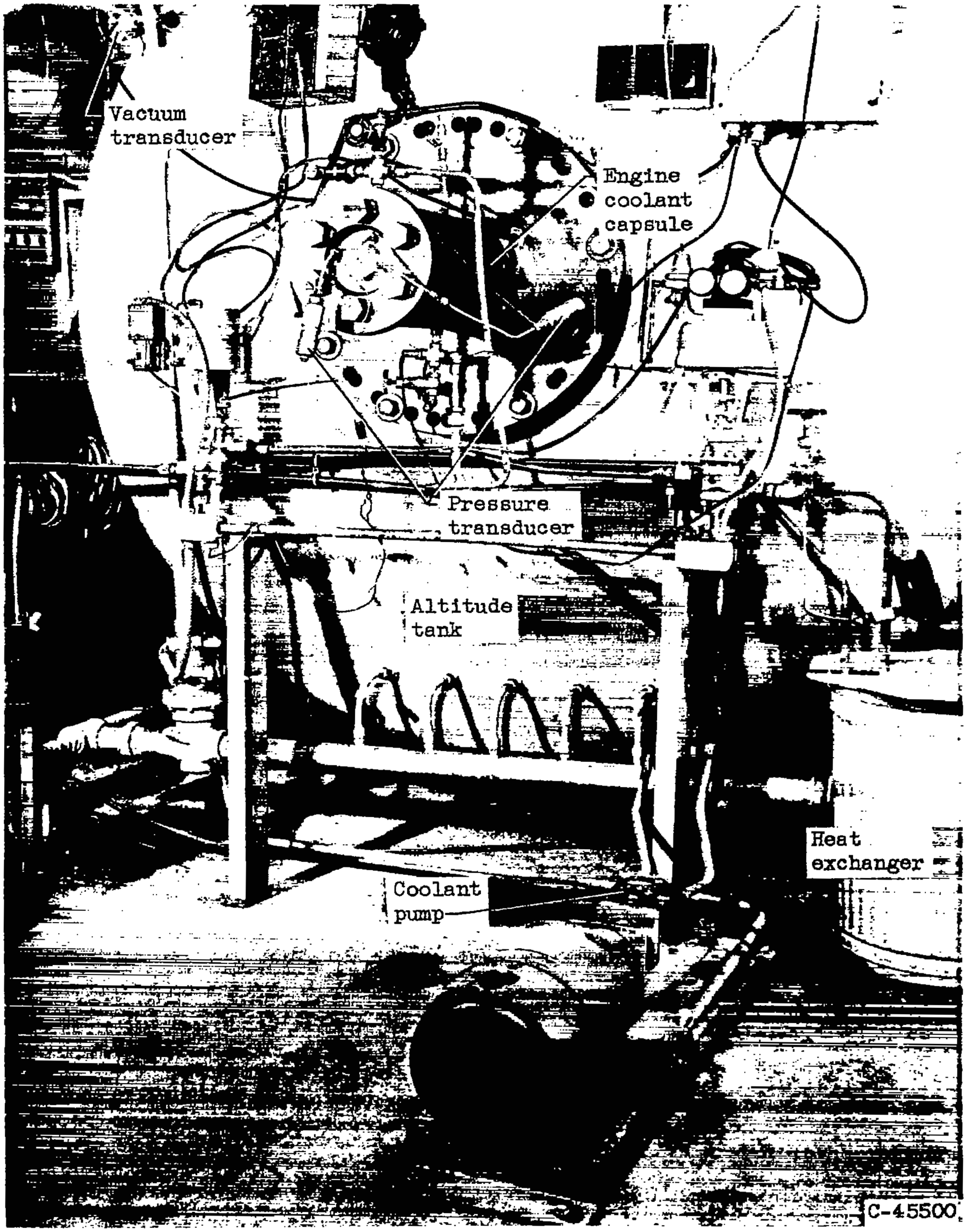

Figure 2. - Altitude tank and coolant system.

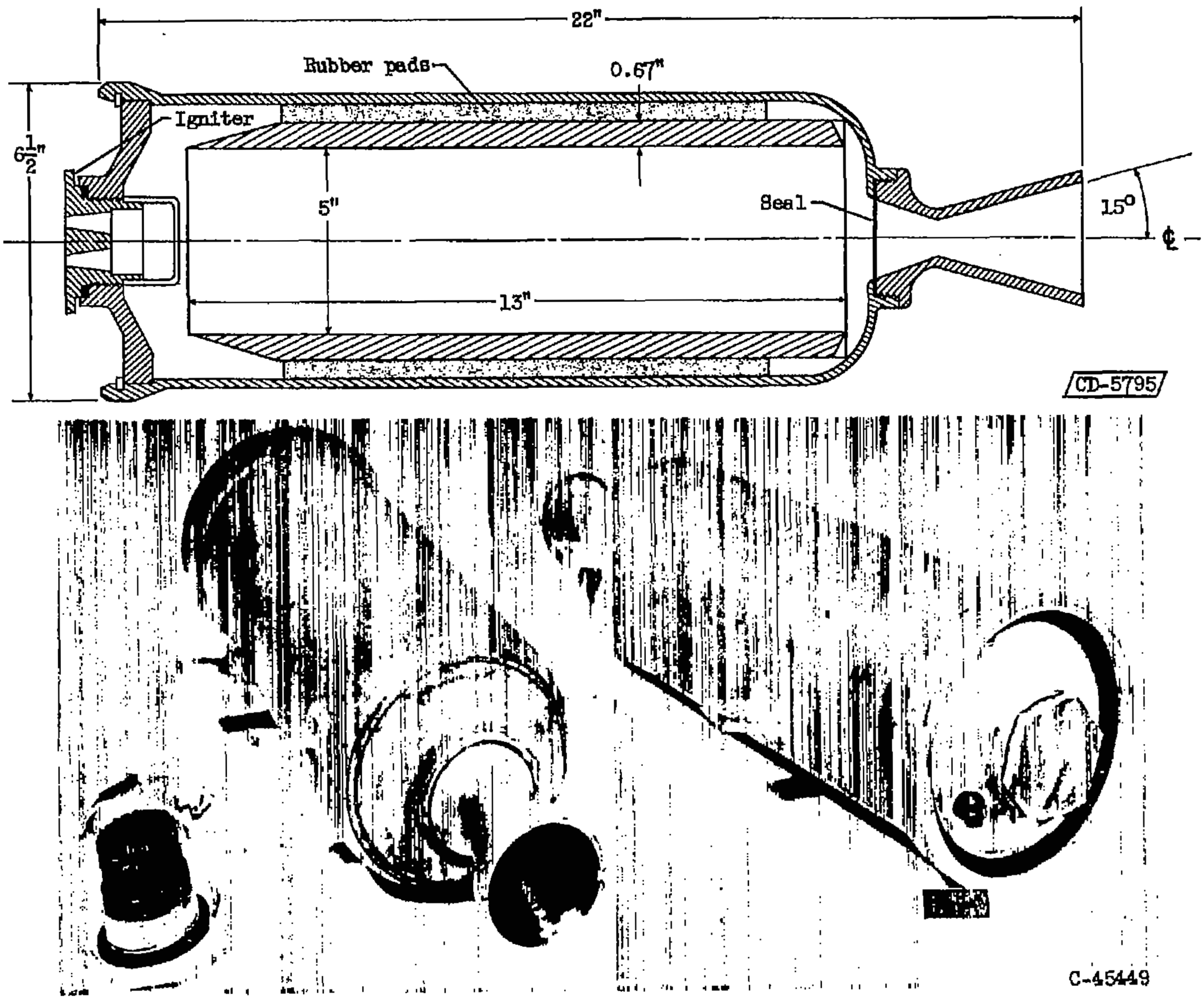

Figure 3. - 1000-Pound-thrust solid-propellant rocket.

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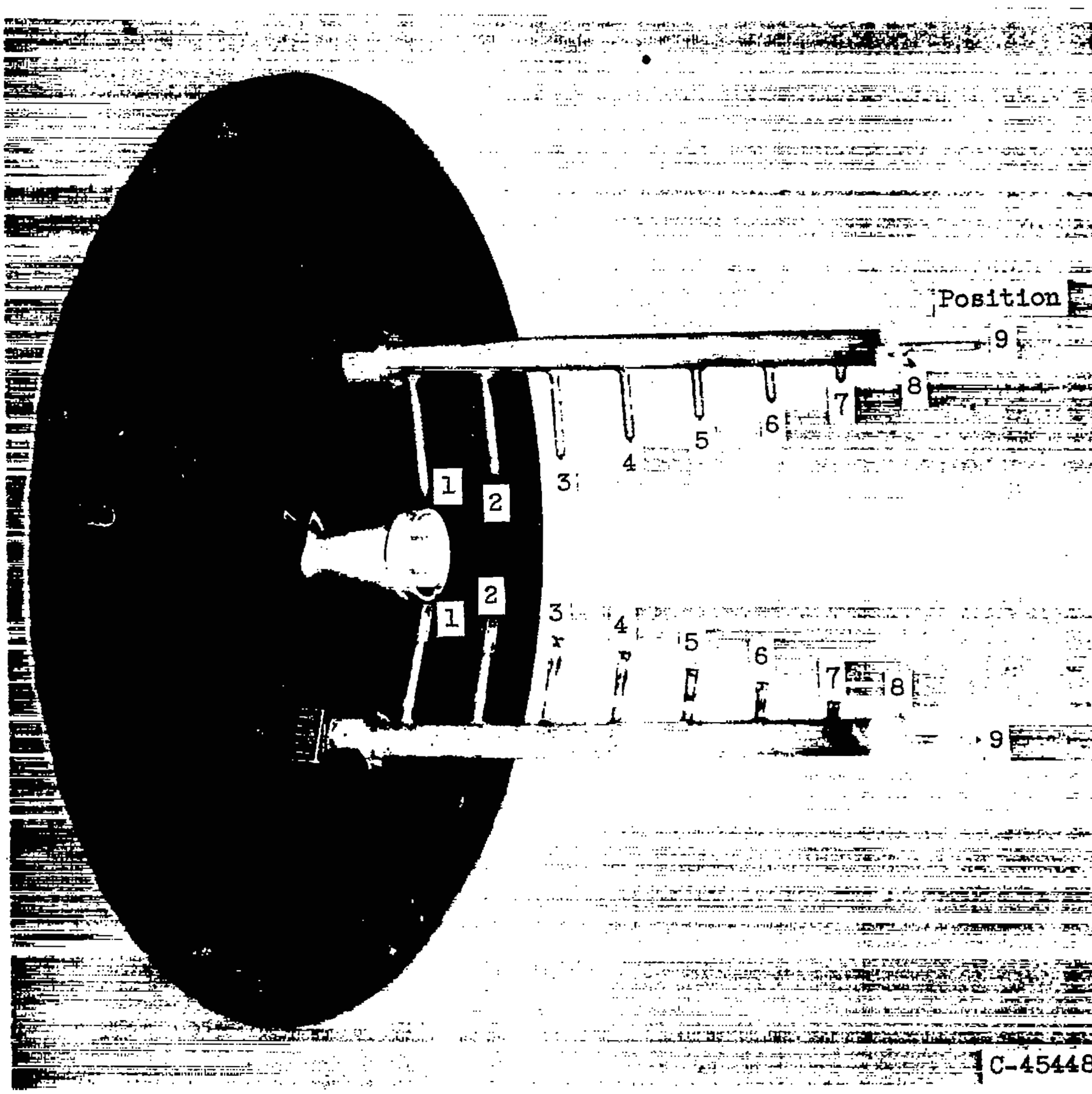
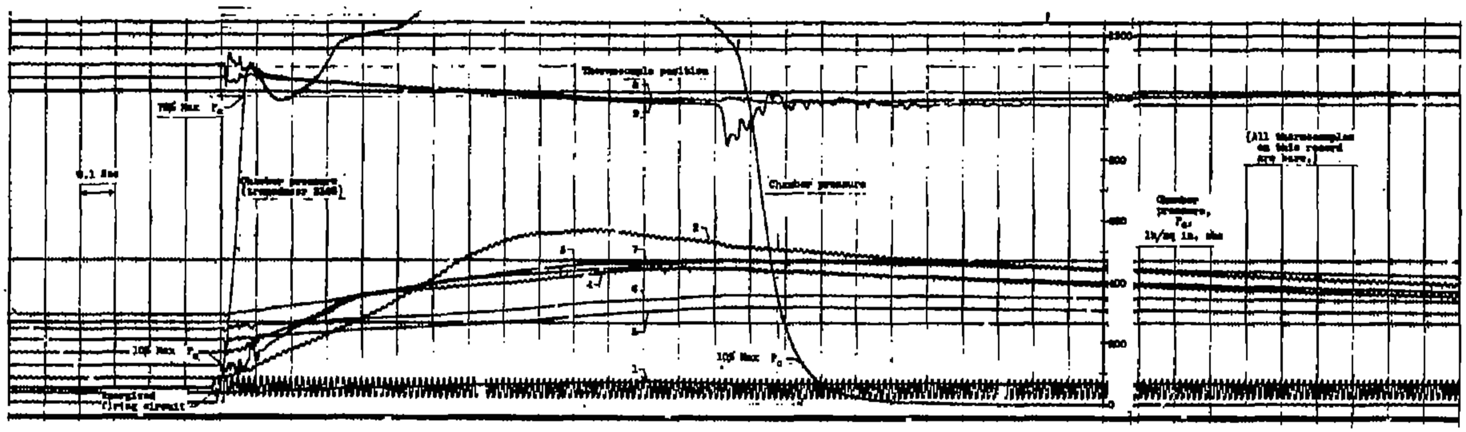
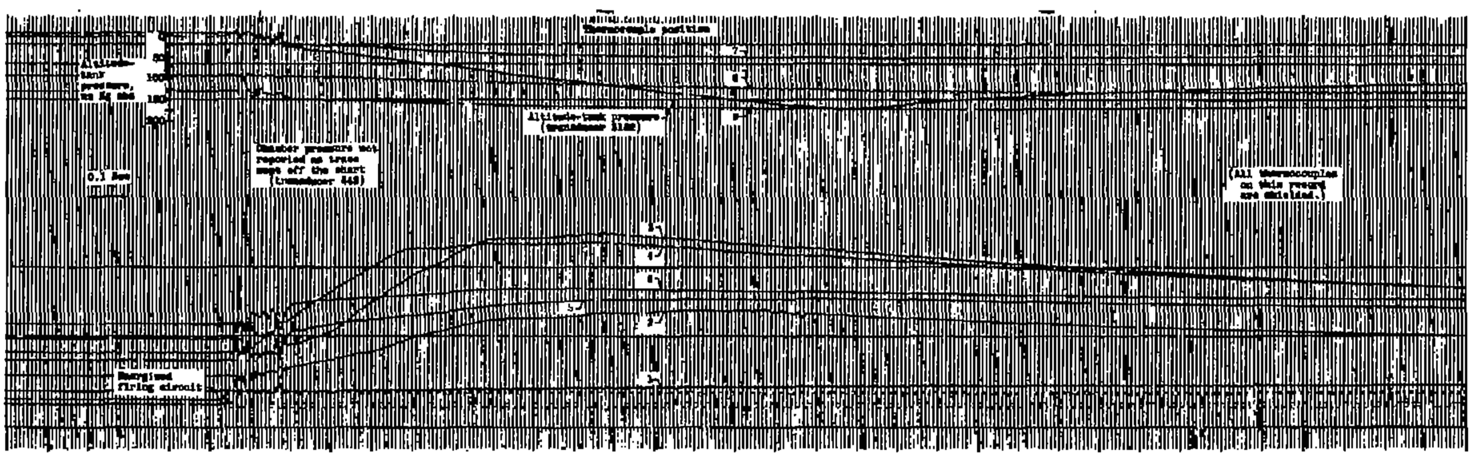


Figure 4. - Thermocouple rakes showing thermocouple position.

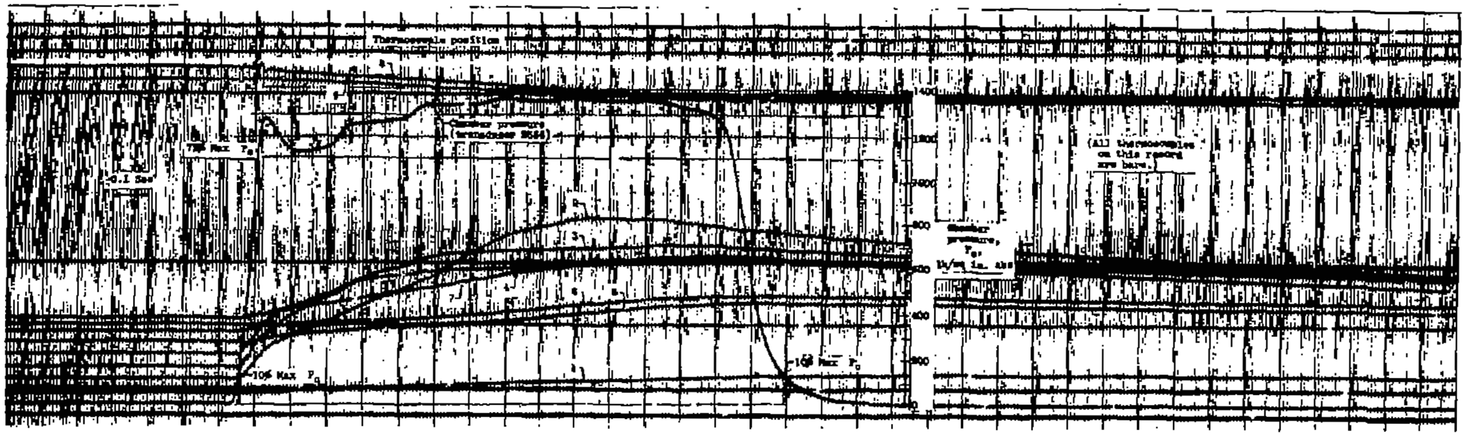


(a) Run 1, oscillograph A.

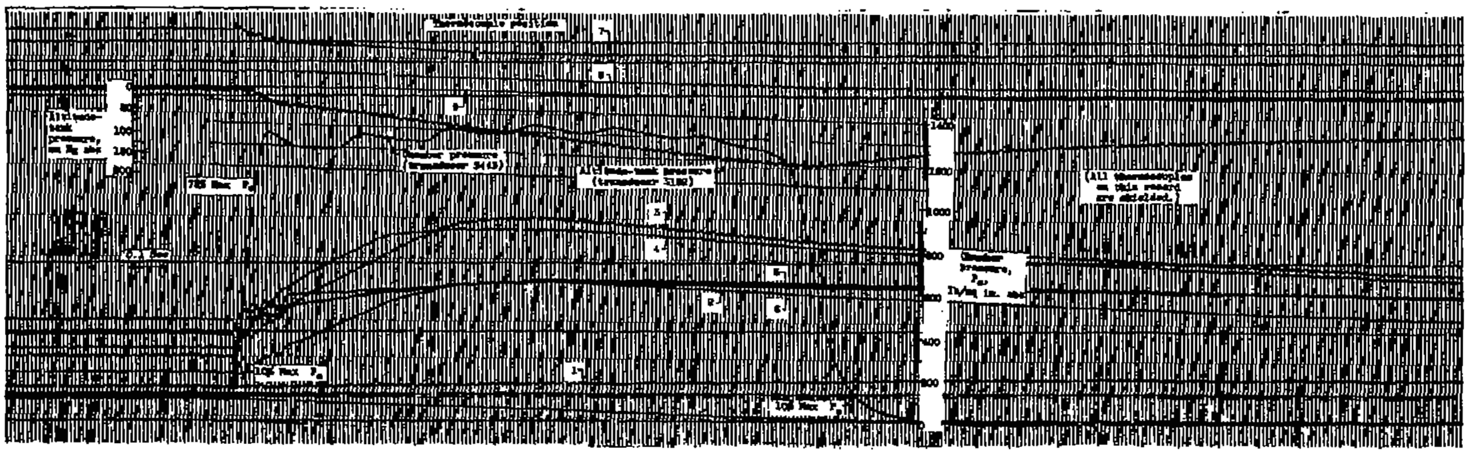


(b) Run 1, oscillograph B.

Figure 5. - Oscillograph records.

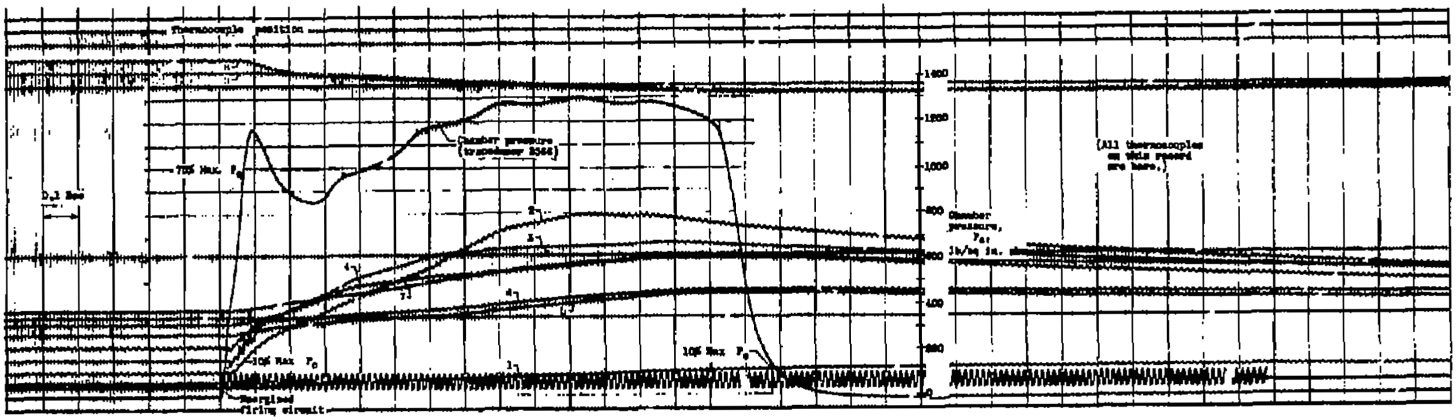


(c) Run 2, oscillograph A.

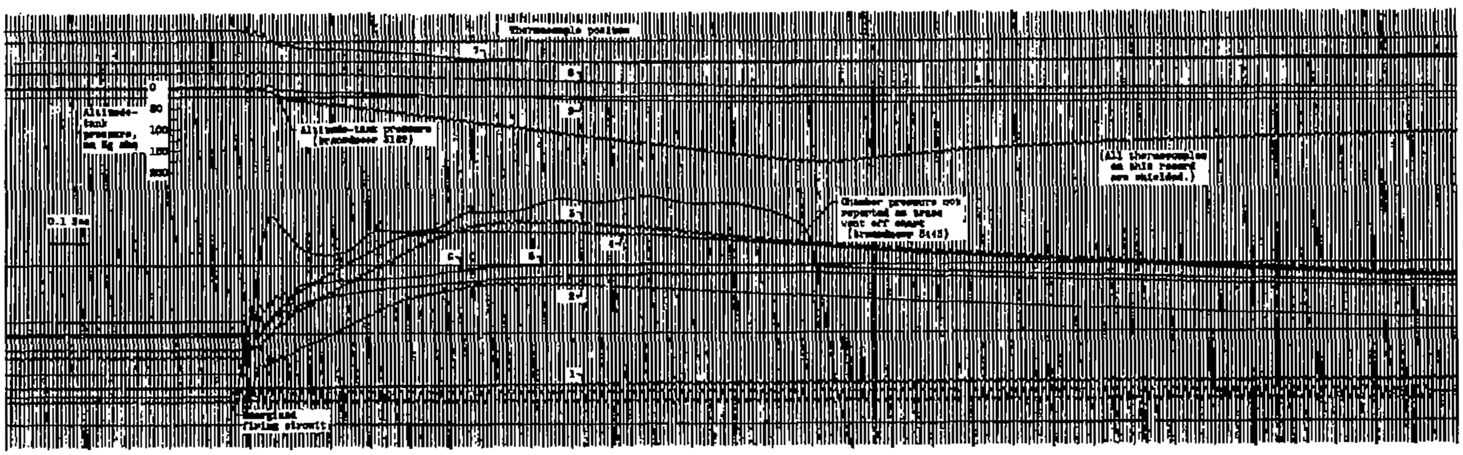


(d) Run 2, oscillograph B.

Figure 5. - Continued. Oscillograph records.

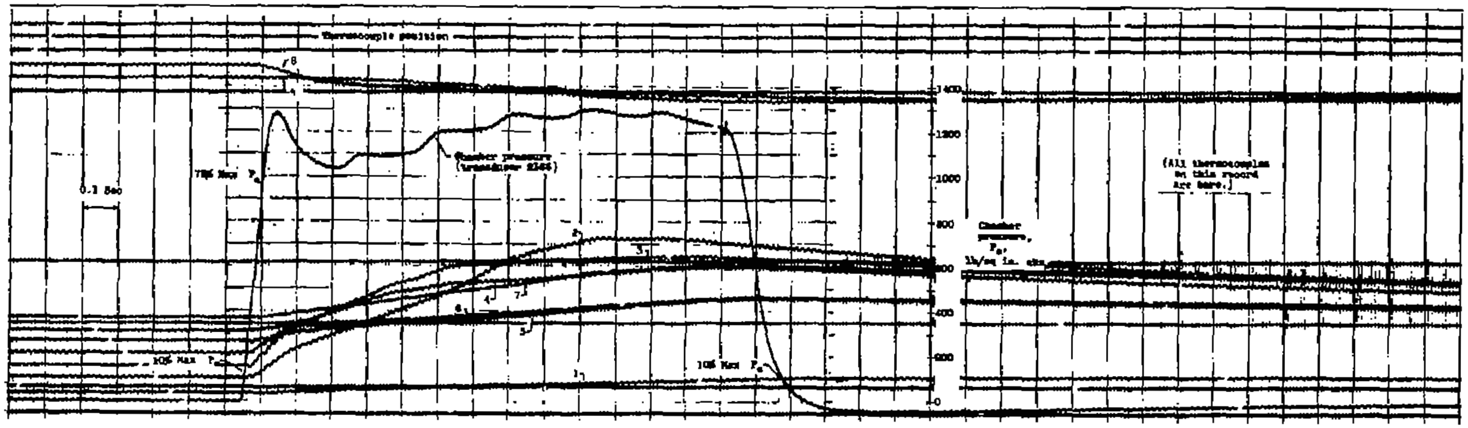


(e) Run 3, oscillograph A.

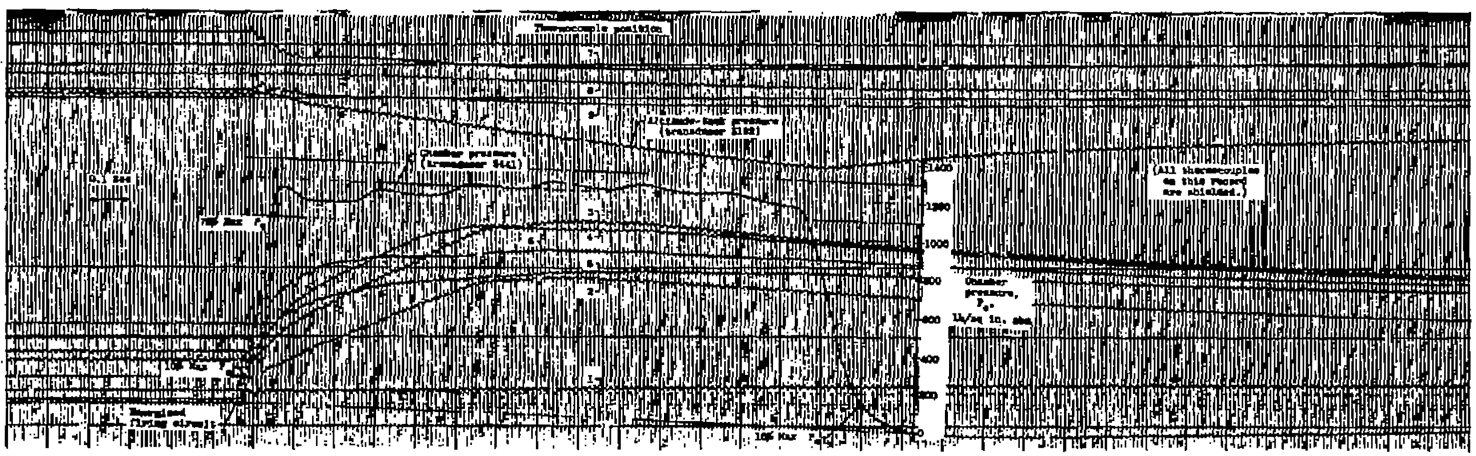


(f) Run 3, oscillograph B.

Figure 5. - Continued. Oscillograph records.



(g) Run 4, oscillograph A.



(h) Run 4, oscillograph B.

Figure 5. - Concluded. Oscillograph records.

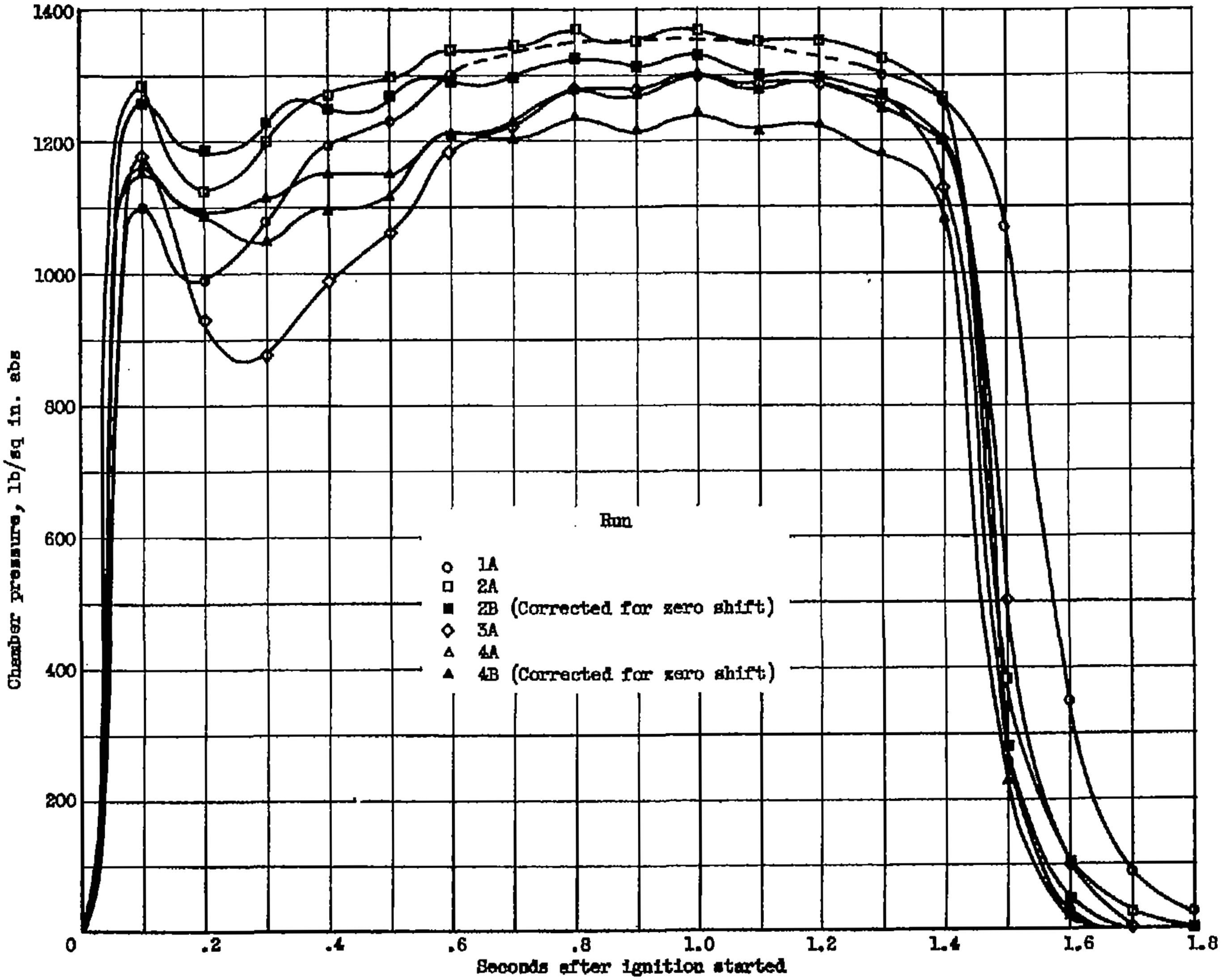
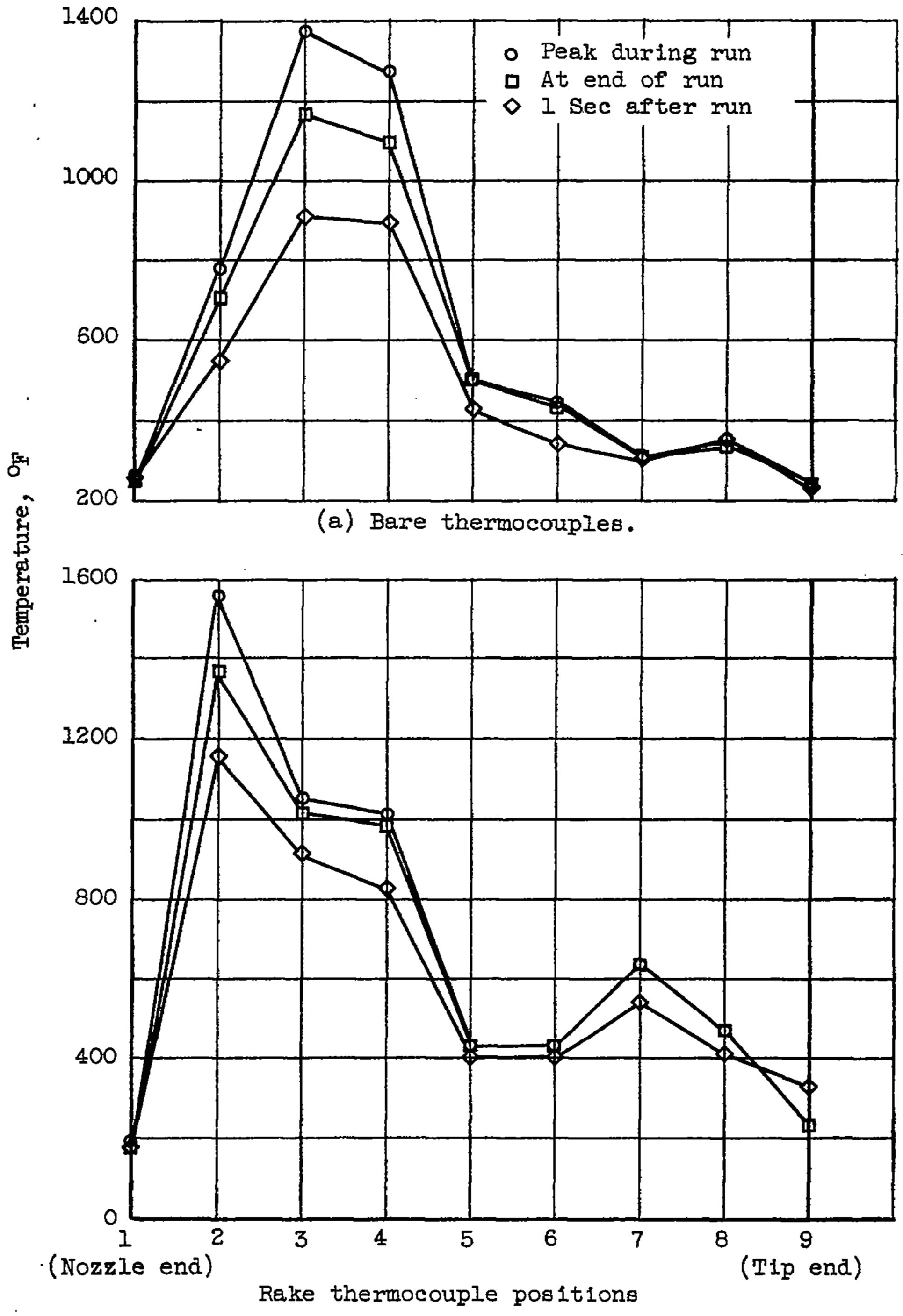


Figure 6. - Chamber-pressure comparisons.



(b) Shielded thermocouples.

Figure 7. - Temperatures in vicinity of rocket jet, run 1.

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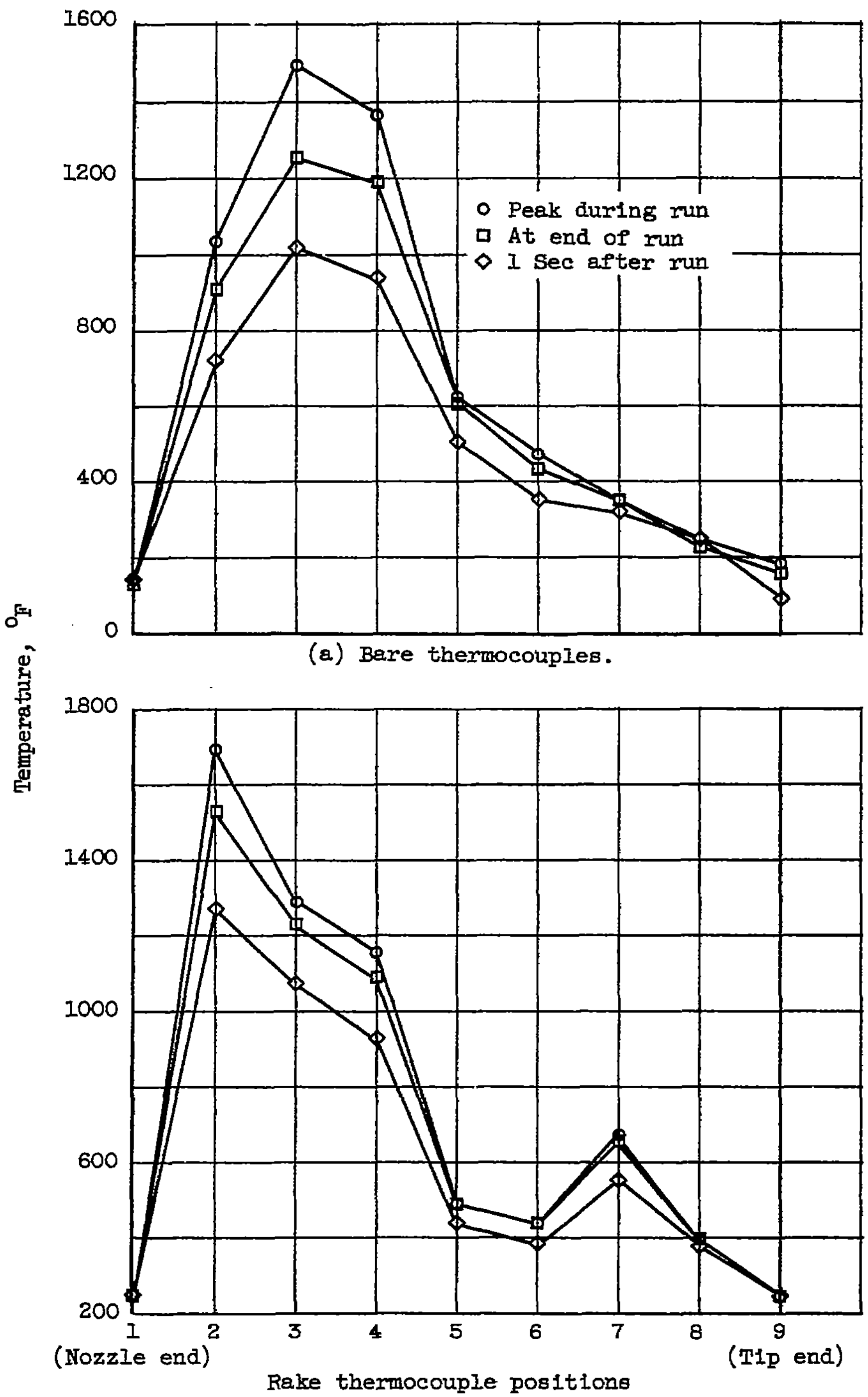

(a) Bare thermocouples.

(b) Shielded thermocouples.

Figure 8. - Temperatures in vicinity of rocket jet, run 2.

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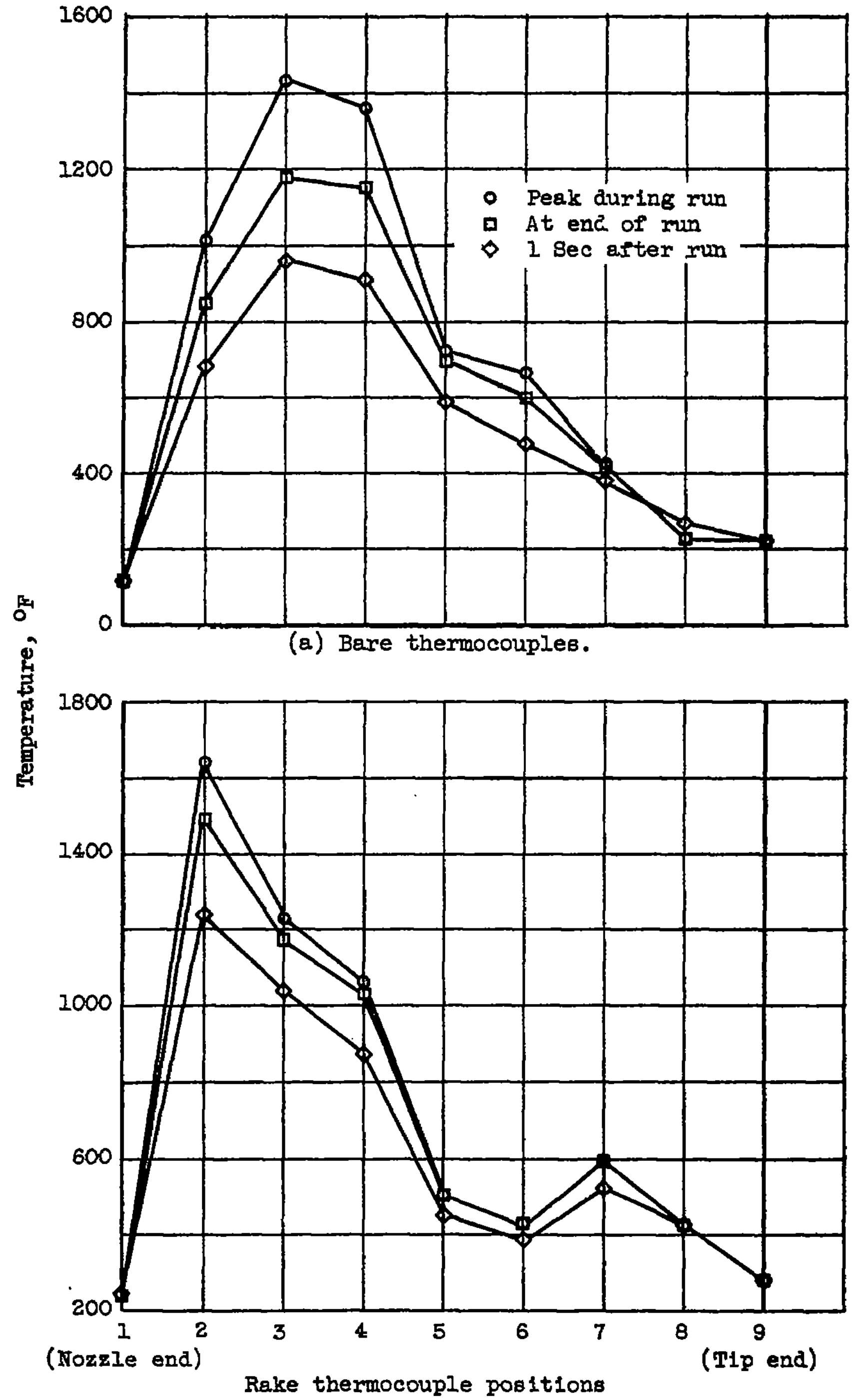

(b) Shielded thermocouples.

Figure 9. - Temperatures in vicinity of rocket jet, run 3.

[redacted]

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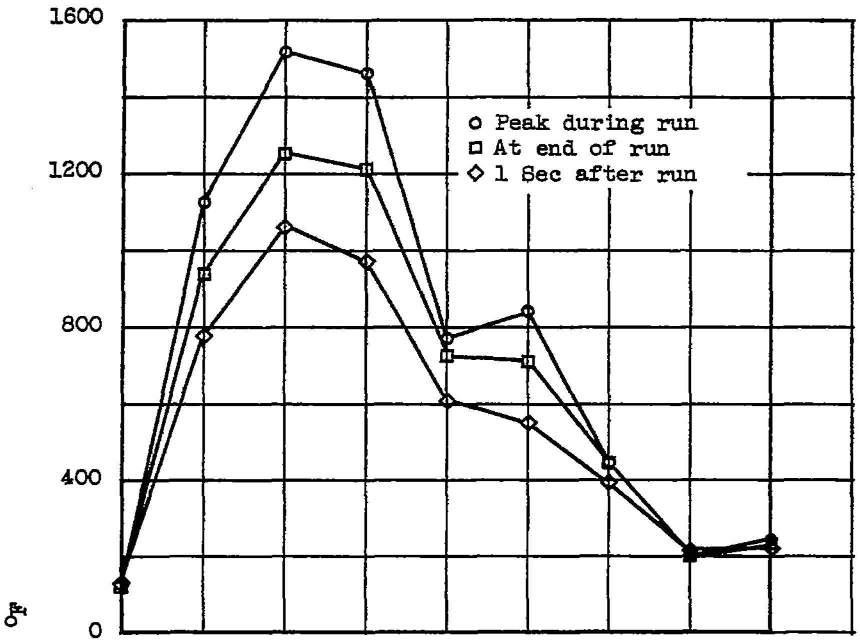
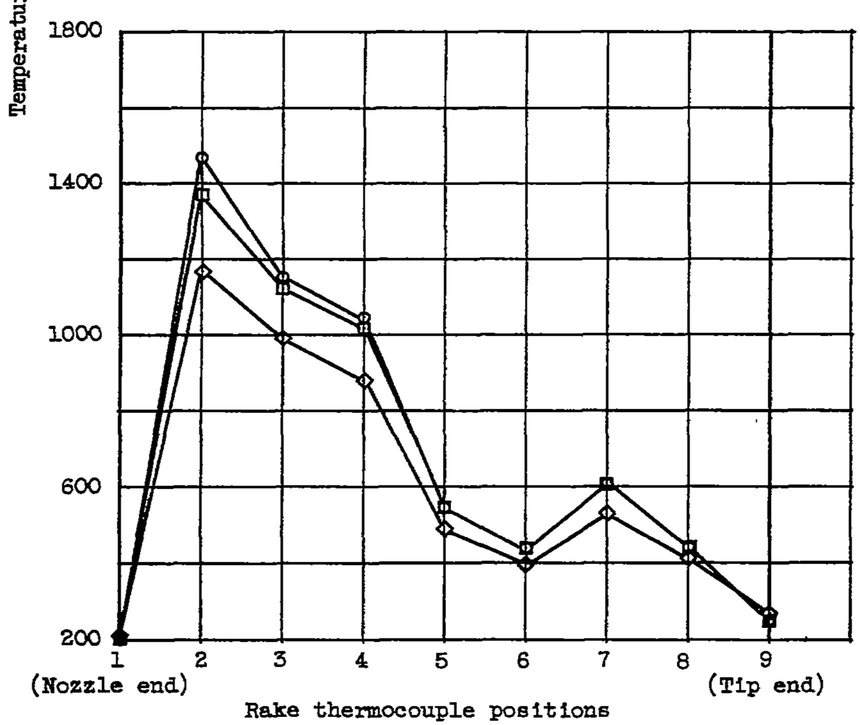


(a) Bare thermocouples.



(b) Shielded thermocouples.

Figure 10. - Temperatures in vicinity of rocket jet, run 4.

[redacted]

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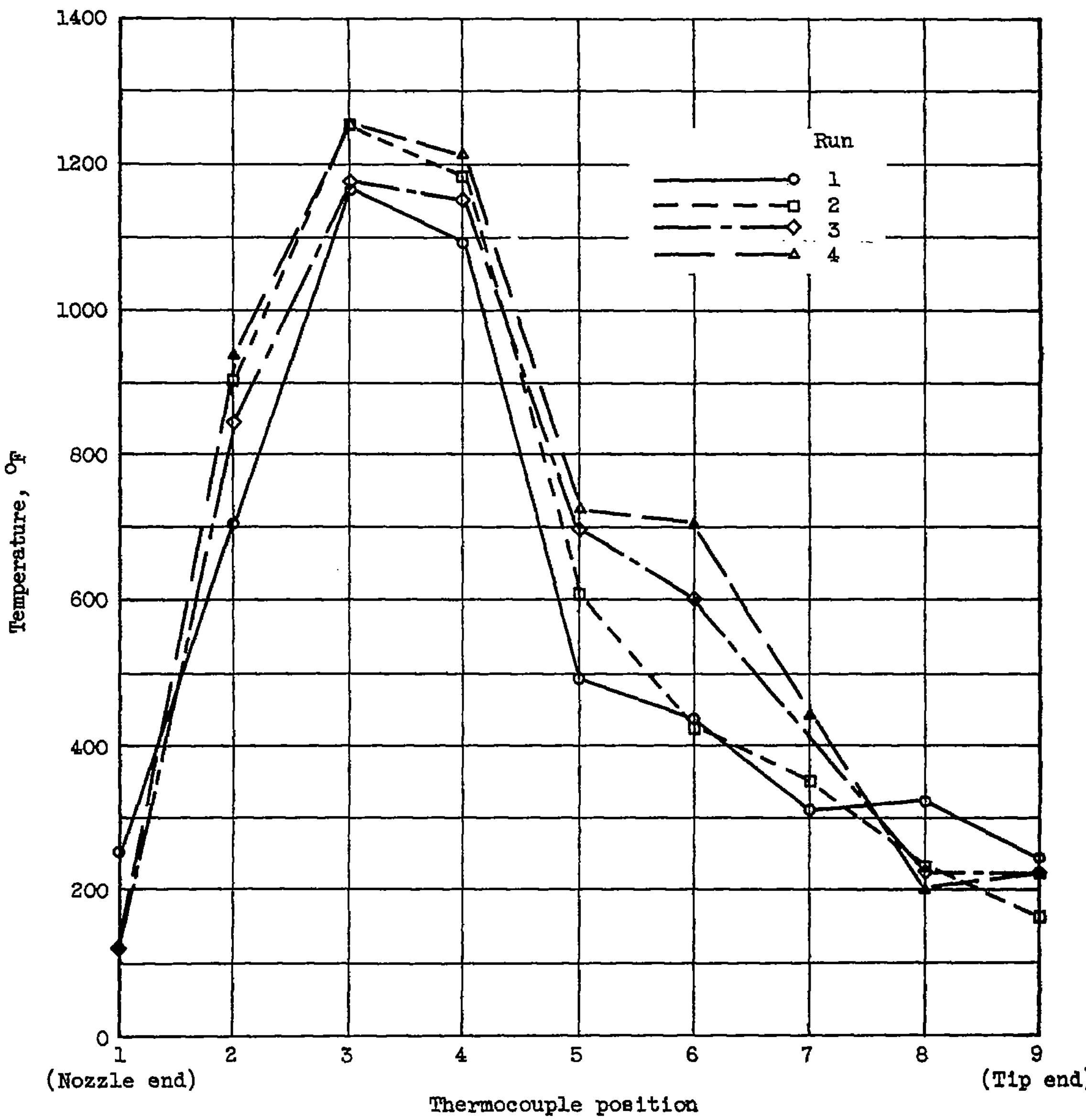

(a) Bare thermocouples.

Figure 11. - Temperatures in vicinity of rocket jet.

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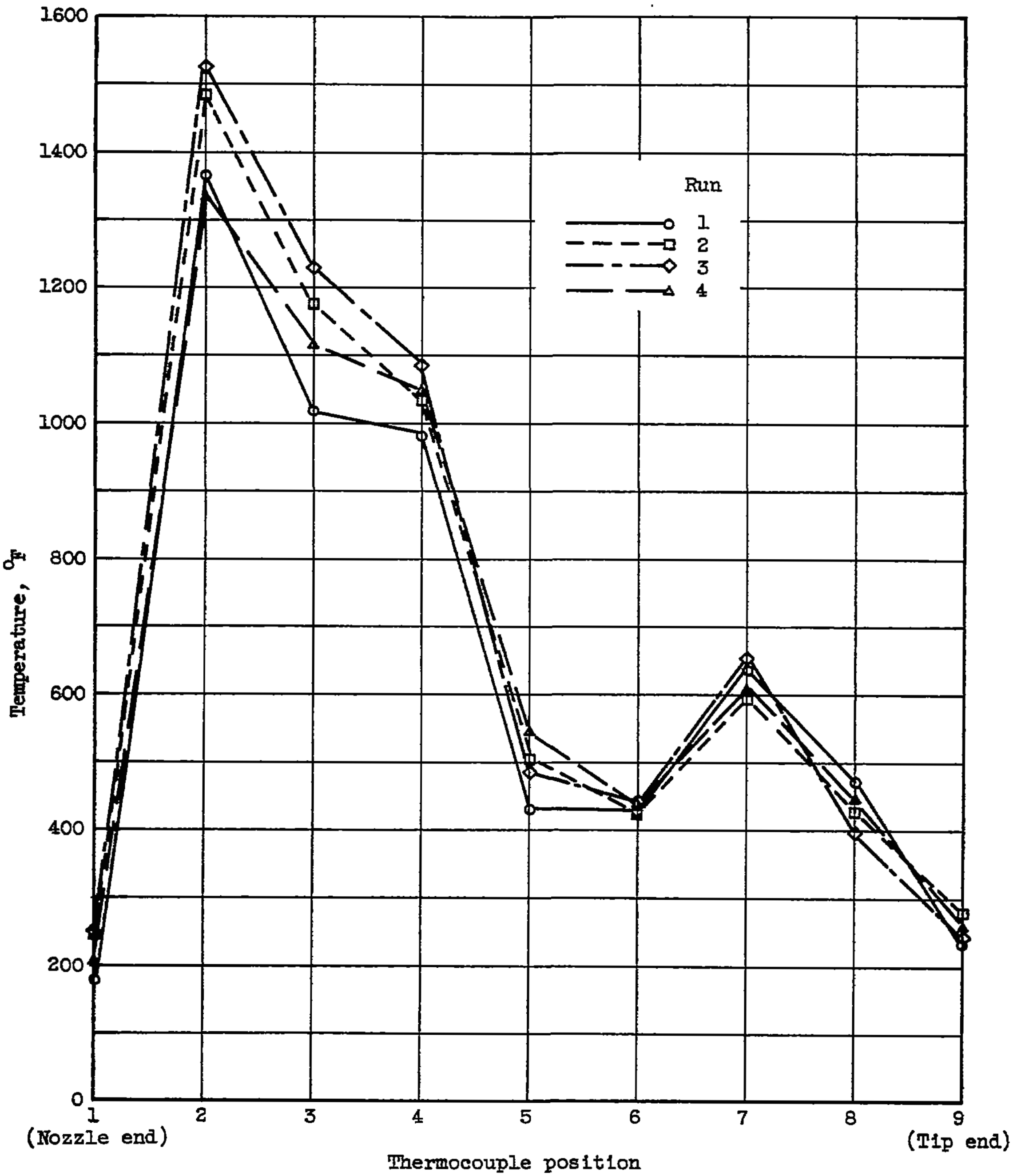

(b) Shielded thermocouples.

Figure 11. - Concluded. Temperatures in vicinity of rocket jet.

ALTITUDE STARTING TESTS OF A 1000-POUND-THRUST SOLID-PROPELLANT ROCKET

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